BATTELLE

Report To

National Aeronautics and Space Administration

Marshall Space Flight Center Huntsville, Alabama

VOLUME III

SUPPORTING RESEARCH AND TECHNOLOGIES LICENSING AND FLIGHT TEST REQUIREMENTS

for

EVALUATION OF THE SPACE DISPOSAL OF DEFENSE NUCLEAR WASTE—PHASE II

to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MARSHALL SPACE FLIGHT CENTER
(Contract Number NAS8-32391)
DPD No. 557, DR No. MA-04

January 31, 1979

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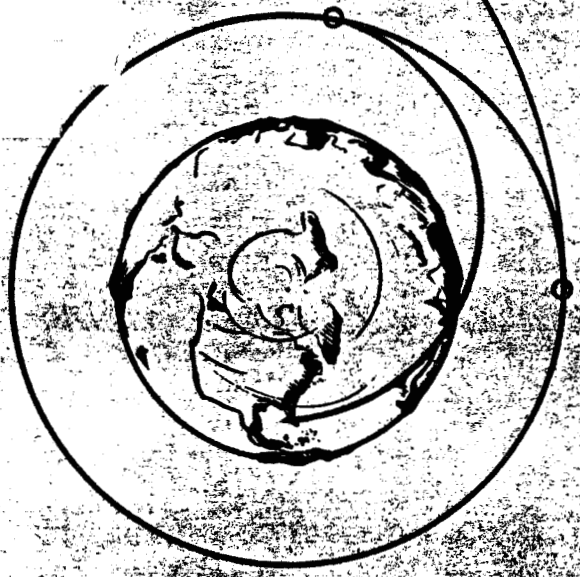
Columbus Laboratories
Columbus, Ohio 43201



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D. S. Edgecombe, Study Leader
Battelle-Columbus Laboratories
Columbus, Ohio

C. C. Priest, COR
NASA/Marshall Space Flight Center
Huntsville, Alabama

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

FOREWORD

The material presented in this report summarizes several program level aspects examined as a part of an overall study of disposal of selected high-level defense nuclear wastes in space. The overall study of space disposal is a continuation of previous NASA and NASA-sponsored study activities, but differs from these previous studies in the emphasis on defense wastes (a study ground rule specified jointly by the DOE and NASA). The study is an integral part of the ongoing NASA/DOE program for study of nuclear waste disposal in space, and was conducted in parallel with efforts at NASA Marshall Space Flight Center; Science Applications, Inc.; and the Jet Propulsion Laboratory. The research effort was performed by Battelle-Columbus Laboratories under NASA Contract NAS8-32391 from February 1978 through January 1979. The major objective of the study was to conduct preliminary analyses of the nature and containment of defense nuclear waste, the safety of the space disposal approach, the environmental impact of selected credible accidents, and various program planning aspects.

Inquiries regarding this study should be addressed to:

C. C. (Pete) Priest, COR
NASA/Marshall Space Flight Center
Attention: PS04
Huntsville, Alabama 35812
Telephone: (205) 453-2796

Donald S. Edgecombe, Study Leader
Battelle-Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone: (614) 424-5087

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1.0 INTRODUCTION

This volume summarizes three separate but related topics relative to defense nuclear waste disposal in space. The first portion of the volume presents the status of supporting research and technology (SR&T)* and the requirements of the concept. Each of the areas is summarized in terms of its status, justification, technical plan, resource requirements and target schedule. Further details regarding this area are contained in Appendix B, which contains excerpts from the 3-year R&D Program Plan developed jointly by Battelle and MSFC personnel. The data in Appendix B were also published separately as a Concept Development Plan.

The second part of this volume discusses likely and preferable licensing approaches for space disposal of nuclear waste. Projections of the possible approaches and specific areas of application of licensing were developed based on Battelle experience, discussions with personnel of the U.S. Nuclear Regulatory Commission, and review of the Interagency Review Group report on nuclear waste disposal. The discussion includes a projected systems development flow chart illustrating the sequence and timing of various licensing events and their relation to other activities such as policy development and environmental assessments.

The final part of this volume discusses the anticipated requirements for flight testing. The projected approach to flight and associated testing is presented, along with a listing of specific suggested test demonstrations and a projected schedule.

*Definition of acronyms and abbreviations are contained in Appendix A.

2.0 SUPPORTING RESEARCH AND TECHNOLOGIES

A 3-year R&D development plan for space disposal has been defined which identifies the various design and technology development activities required prior to a decision to proceed with development. As a part of that plan, a general listing of areas requiring either technology development, testing or both were developed ("Critical Technology Experiments/Testing Plan" of Appendix B of this volume). This section defines the required technology developments which will have to be undertaken as a part of the supporting research and technology (SR&T) program for space disposal of nuclear waste. Each of the developments is summarized in terms of its status, justification, technical plan, resource requirements and target schedule.

A distinction needs to be made between technology developments and design problems. Many of the elements of the space disposal system (OTV, SOIS, container, docking system, etc.) do not currently exist, and would need to be designed, developed and tested. However, none of these developments would necessarily require the creation of any new technology. As an example, the OTV and SOIS would use hydrogen/oxygen and storable liquid propellants, respectively. The technology for both of these propellants is well developed and systems using them have been built and flown operationally (e.g., Centaur for H_2/O_2, Viking for storables). This discussion concentrates on those areas where such technology is not presently available and needs to be developed as part of the overall program.

It has been stated that space disposal of nuclear waste is primarily an engineering problem, based largely on existing technology. This statement is substantiated by the material of this discussion. Only four primary areas of technology development have been identified, and for one of these, it is not certain at this time that it is needed. The three areas where technology development is definitely needed are:

- Waste concentration processes
- Waste form thermal response
- Remote automated rendezvous and docking.

The fourth area where new technology may be needed is the long-term behavior of materials in a deep space environment.

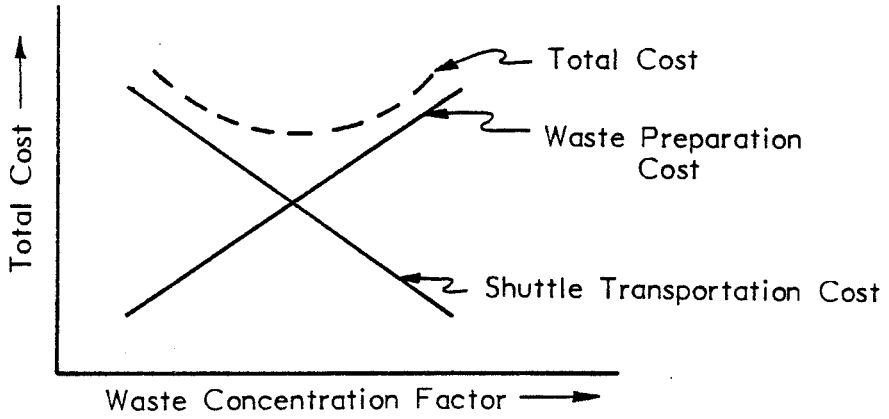
2.1 Waste Concentration Processes

2.1.1 Status

The status of defense nuclear waste concentration processes is discussed in detail in Section 3 of Volume II. Defense nuclear waste currently exists in large quantities of dilute materials in storage at three different sites in the United States. Preliminary treatment processes have been defined for these wastes which would be suitable for terrestrial disposal, but which would not give adequate concentration for space disposal. Processes for further concentration have been defined, but are based on laboratory scale experiments and have not been verified as applicable in the scale envisioned. Further definition and demonstration of these proposed processes is required.

2.1.2 Justification

The number of Space Shuttle flights required to dispose of defense nuclear waste is directly related to the degree of concentration achievable. Unless adequate concentration can be achieved, the number of flights required may be prohibitive (see Figure 3-4, Volume II). It is expected that the cost of concentration will increase proportional to the degree of concentration required. Therefore, there is probably an intermediate level of concentration that minimizes overall cost (see below).



Better understanding of the potential waste concentration processes are required to determine this mininum cost point.

2.1.3 Technical Plan

Concentration processes need to be developed for Hanford, Savannah River and Idaho defense waste. For Hanford, a process based on dissolution in molten caustic followed by treatment with nitric acid may be feasible and adequate for treatment of four of the five types of sludge stored there. The zirconium sludge is insoluble in molten caustic, and removal of significant amounts of inert materials would require development of a new (not yet defined) concentration process. Adequate concentration could probably be achieved if the caustic/nitric acid process were developed. Development of a process for the zirconium sludge would allow additional concentration or would provide a margin in case of problems with the other process.

For Savannah River, a single process involving successive washing with caustic and oxalic acid has been proposed and should be developed and demonstrated.

For Idaho Falls, a method for dissolving the calcined wastes must be developed. Dissolution chemistry has been under development at Idaho Falls, and a process involving dissolution with nitric acid and molten sodium bisulphate has been proposed. This process or an alternative needs to be developed and demonstrated.

2.1.4 Resource Requirements

Development and demonstration of the various concentration processes described above are estimated to require significant commitment of resources. The 3-year plan calls for an expenditure of over $2 M in the general area of Nuclear Waste Definition and System Design. Concentration process development is expected to require nearly half of these resources, or approximately $1 M to develop to a point where the first major NASA/DOE decision on space disposal could be made with confidence.

2.1.5 Target Schedule

Because of the significance of achievable concentration on the overall feasibility of space disposal, concentration technology development should be initiated as soon as possible. Bearing unexpectedly early resolution of the

associated problems, the program will need to extend over the 3-year period leading to the first NASA/DOE decision point on space disposal. Therefore, a projected schedule is as follows:

1ST YEAR	2ND YEAR	3RD YEAR
200 K	400 K	400 K.

2.2 Waste Form Thermal Response

2.2.1 Status

Preliminary definition of potential defense nuclear waste forms has been accomplished (see Section 3 of Volume II). Some of these forms are well developed (e.g., calcine) while other forms have received less attention (e.g., compartmented calcine). At the present time, a final choice of waste form cannot be made. Further development of the characteristics of these forms is required, particularly regarding thermal characteristics such as dispersion formulation of inhalable particles under high temperature reentry environments.

2.2.2 Justification

Preliminary accident analyses indicate that the defense waste payload may be subjected to severe thermal environments which could lead to release of nuclear waste. The environmental effects of these accidents could be reduced significantly if the waste form were resistant to dispersion under these severe thermal environments and if the waste form were such that the dispersed material contained a minimum amount of inhalable particles.

2.2.3 Technical Plan

Waste forms with the desirable characteristics need to be developed and tested on a laboratory scale. The dispersion and particle formulation processes will need to be examined under two conditions:

(1) Exposure to extremely high temperature sea level environments over extended periods of time, simulating on- or near-pad fires, and

(2) Exposure to high velocity, high temperature gas flows, simulating reentry from orbit.

In both cases, small samples of the waste forms need to be exposed directly to the thermal environment, simulating waste in an exposed state due to container breachings from mechanical (e.g., fragment impact) or thermal (melting) causes. The waste melting and dispersion rates and the resulting particle size distributions need to be determined for each candidate waste form.

2.2.4 Resource Requirements

This activity properly falls under both the categories of Nuclear Waste Definition and Critical Technology Experiments/Tests, covered under Appendix B. Preparation of the candidate waste forms probably is nuclear waste definition, while the thermal response and particle formulation tests are a critical technology test. DOE funding for these two areas totals $2.3 M and $1.5 M, respectively. For the space specific program of waste form thermal response testing, funding of $200 K - $300 K would probably be required, depending upon the number of forms to be tested.

2.2.5 Target Schedule

Testing of the waste form probably does not need to begin until further progress is made in defining the degree of achievable waste concentration, since detailed development of the waste form would not be required until it was relatively certain that desirable concentrations can be achieved. Therefore, the waste form testing program probably should not be initiated until the second half of the 3-year program outlined in Appendix B. A tentative schedule, based on an 18-month program, is shown below.

1ST YEAR	2ND YEAR	3RD YEAR
-	$100 K	$200 K

2.3 Remote Automated Rendezvous and Docking

2.3.1 Status

Various portions of the contingency plans for space disposal of nuclear waste would require a remote rendezvous and docking capability (e.g., rescue of a payload from an unplanned orbit). NASA has never conducted an automated rendezvous and docking. However, the Soviets have conducted numerous automated dockings in near-Earth orbits, and some proposed NASA planetary missions (e.g., Mars surface sample return) could require distant automated rendezvous and docking. Although some of the hardware elements required for this operation may already exist (e.g., transponders, aircraft-type search radars), a complete demonstrated technology base does not currently exist.

2.3.2 Justification

Demonstrated system safety will be a key requirement for obtaining public acceptance of any nuclear waste disposal approach. For space disposal, the ability to work around unplanned events or accidents will be the key to such safety. A remote rendezvous and docking capability will be an essential element of the space disposal safety approach.

2.3.3 Technical Plan

During the projected 3-year period prior to the first major DOE/NASA decision on space disposal, the basic approach, required hardware elements and supporting performance analysis need to be developed. If any key technologies are identified which do not exist, development of these technologies should be pursued. Examples of possible key items needing development include:

- Lasar radar for distant acquisition of a non-responsive nuclear payload
- Software logic for autonomous rendezvous and docking with intermittent ground control monitoring and override (for near-Earth rescues, a continuous man-in-the-loop system is probably feasible and desirable).

The study should be conducted in two parts. First, the basic logic and analysis base for the rendezvous and docking approach should be established. Then, the required technologies should be establishd and areas requiring development should be identified. This identification should include specification of performance requirements that the technology developers and hardware designers can respond to.

2.3.4 Requirements

It is difficult to project the amount of resources that might ultimately be required for this area. For the 3-year period discussed in Appendix B, the funding would come from the Critical Technology Experiments category. The projected funding is $300 K.

2.3.5 Target Schedule

The program should be conducted in two parts of roughly equal length (approximately 18 months). The funding for each part should also be roughly equal, resulting in the schedule shown below.

	1ST YEAR	2ND YEAR	3RD YEAR
Activity	Analysis	Analysis/Technology Definition	Technology Definition
Funding	$100 K	$50 K/ $50 K	$100 K

2.4 Long-Term Behavior of Materials in a Deep Space Environment

2.4.1 Status

The state of knowledge of materials behavior under long-term space exposure is currently quite limited. Some knowledge of behavior over short periods ot time (5-10 years) has been gained through operational spacecraft experience and special events such as the reexamination of Surveyor by the Apollo astronauts. Further such experience is expected from the Long Duration Exposure Facility (LDEF). No data exist for the lengths of times discussed for solar orbit residence of nuclear waste (100,000 to 1,000,000 years).

2.4.2 Justification

It is not clear that a program to develop materials resistant to a long-term space environment is required. The determination of whether this is a requirement is an objective of the activity identified here. If it is shown that early release of waste material in solar orbit would constitute a significant risk to the Earth environment, a program to develop such materials would be needed to help ensure overall system safety.

2.4.3 Technical Plan

The technical plan for this area must be conducted in two parts. First, an analysis of the potential consequences of early release of the waste material must be conducted. This should consider such items as transport mechanisms from solar orbit to the Earth's biosphere, the potential form of the waste after exposure to the deep space environment, and the potential environmental consequences of Earth reencounter.

Should this first analysis indicate a potential hazard of sufficient magnitude to warrant further steps, a second study phase should be conducted to identify steps for reducing the hazard. These steps will deal primarily with the materials associated with the waste payload, both the container and the waste forms. Potential materials use that would delay and/or reduce the waste release or which would result in release of the material in a form less potentially

hazardous should be identified. The study should also address the means for verifying the materials properties (e.g., accelerated aging testing).

2.4.4 Resource Requirements

This activity would be conducted under the Critical Technology Experiments and Impact Assessment categories of the 3-year plan shown in Appendix B. It is expected that approximately $100 K would be required for the preliminary analysis, and an additional $100 K for the second part, if it is required.

2.4.5 Target Schedule

Because of the potential difficulties of technology development in this area, and because it would be desirable to know as soon as possible whether this is a problem area, the study identified here should be conducted as soon as feasible. The proposed schedule is shown below.

	1ST YEAR	2ND YEAR	3RD YEAR
Activity	Impact Assessment	Materials Identification	Possible additional development
Funding	$100 K	$100 K (if required)	Level to depend upon results of 1st and 2nd year activities.

3.0 LICENSING REQUIREMENTS

3.1 Introduction

The space augmentation of defense high-level waste (HLW) disposal will require the development of new processes and construction of new facilities. These processes and facilities will be used to retrieve the waste from its current storage location, concentrate it to increase its specific activity, solidify it for packaging and shipping, prepare the waste payload for placement in the Space Shuttle vehicle, launch the waste payload into Earth orbit, and transfer it to solar orbit using an OTV/SOIS. These activities can logically be divided into two major systems: (1) the retrieval, waste treatment, and payload fabrication system at the current defense waste storage sites; and (2) the payload preparation and launch system at the launch site.

The purpose of this discussion is to address the licensing and policy questions which must be answered before proceeding with the space disposal option. In all cases we are talking about government owned material at government facilities being placed ultimately in solar orbit.

The discussion will present first a general conceptual outline of the problem and procedure, the specific licensing questions on specific systems will then be addressed, the criteria development requirement will be discussed, as will the data requirements, and finally, the policy decisions which must be addressed.

The material contained in this section has been developed through a consideration of existing regulatory practices, likely future changes in these practices, and the unique nature of space disposal. Discussions with appropriate personnel at the United States Nuclear Regulatory Commission and the Jet Propulsion Laboratory (JPL) were most helpful.[3-1,3-2] Considerable use was made of the recent reports of the Interagency Review Group (IRG)[3-3], the draft final JPL report[3-4], and other recent publications[3-5,3-6,3-7].

3.2 Overview

The four primary areas of concern in developing the space disposal option are:

(1) The development and construction of the waste treatment and payload fabrication preparation facilities

(2) The development and construction of the launch site facilities

(3) The development of standards, criteria, and regulations for the space disposal option

(4) The major policy decisions required to allow the space option to proceed.

The interaction of these major areas is shown in Figure 3-1. The requirements for environmental impact statements and NRC licenses are included in the figure since an NRC license is expected to be required for all systems of HLW disposal.[3-1]

Since NRC licensing will be required, the question of the type of license and the regulations required will be addressed for each system. Since current regulations may address a concept in one manner while new or changing regulations may be different, the question of licensing will be somewhat speculative, but as many options as possible will be covered in the discussion.

Several major policy decisions will be required at different steps along the way. These become points at which "go, no go" decisions are made. After the decision is made to continue investigation of the space disposal option, a draft environmental impact statement for the space disposal program will be required. At the same time, the development of standards, criteria, and regulations can begin. The regulations will have an important impact on the licensing requirements for the overall system.

Also, since the retrieval, concentration, and solidification of the waste material will be required, research and development of techniques for these operations should proceed. Retrieval, for example, will be required for any HLW disposal method requiring movement of the waste. The most novel or different part of the space option is the concentration requirement and perhaps even some chemical or isotopic separations.

The ground transportation of the loaded waste containers from the payload fabrication facility to the launch site requires no special licenses or

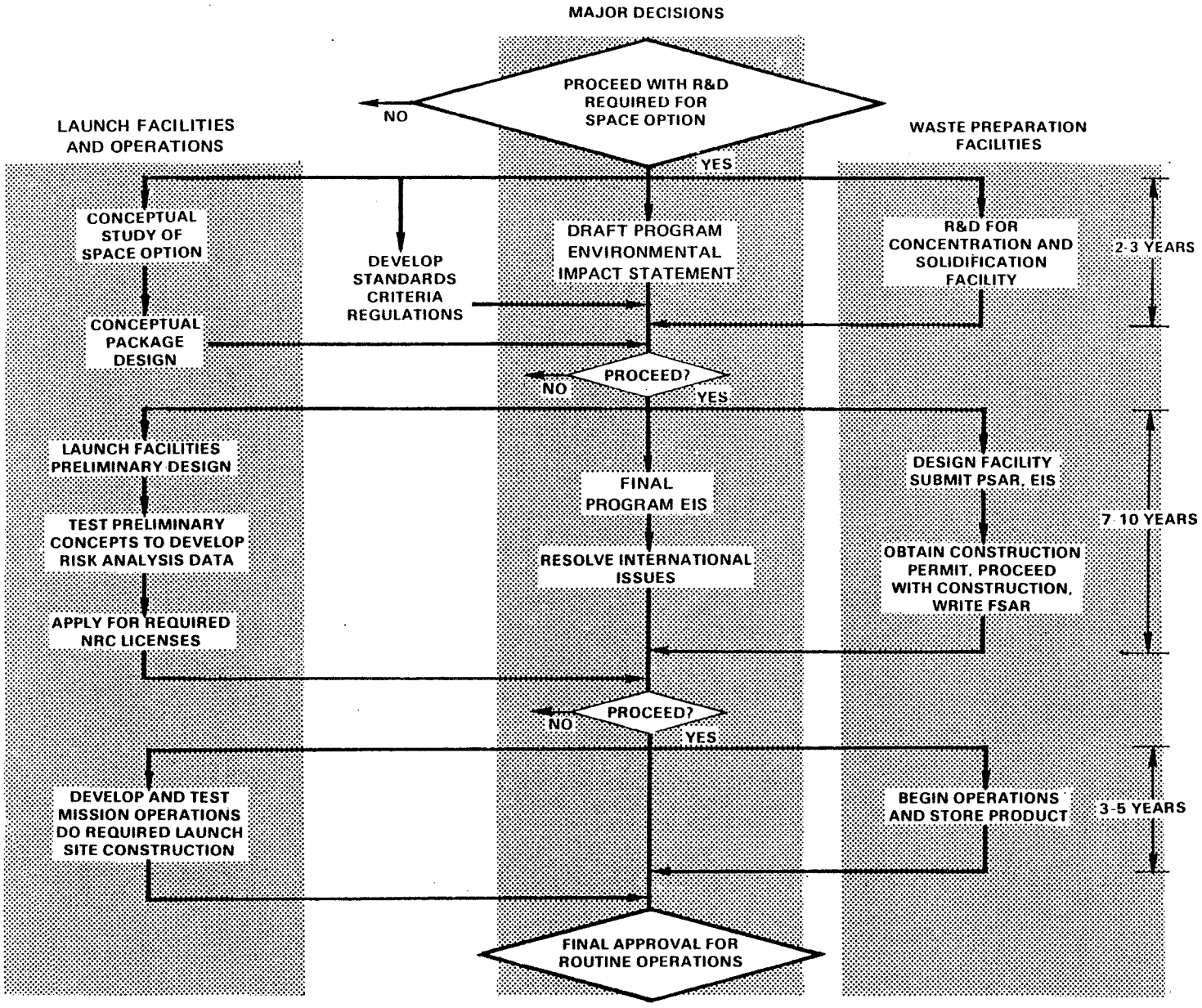


FIGURE 3-1. INTERACTION OF LICENSING WITH OTHER MAJOR DECISION AREAS

analysis beyond those required by current regulations. The shipping container can be built to the standard requirements given in 10 CFR 71.(3-8)*

The launch site facilities present a totally new problem as far as regulation and criteria are concerned. This problem will be discussed in the section on the launch site.

* Existing United States Nuclear Regulatory Commission (NRC) regulations are quoted frequently in this section. 10 CFR 71 refers to Chapter 71, Title 10, Code of Federal Regulations - Energy. See Reference 3-8 for full title.

3.3 Waste Treatment and Payload Fabrication Facilities

The waste treatment and payload fabrication facilities include the system for recovery of the liquid wastes from storage, concentration of the waste to an allowable or economic specific activity, solidification of the waste, and loading of the waste in a specified container. This system would be much like the systems anticipated to be used in fuel reprocessing plants. Since these facilities must be integrated with each other, it is expected that they will be contained in a single building or complex of buildings and be licensed as a single system. The criteria for the payload would be specified by the environmental and technological considerations of the disposal operation.

The waste treatment and payload fabrication facilities must have facilities for storage of loaded waste containers (payload). It is unlikely that the most efficient method of operation will produce the product at a rate identical to the shipping and ultimate disposal rate. These facilities are similar to the waste handling operations envisioned for a commercial fuel reprocessing plant. It is normally expected that the design, licensing and construction of such a plant would take 7 to 10 years. However, it should be noted that no licensed facility of this type is now in operation.

Since the defense HLW is stored at DOE sites, it is expected that the waste treatment and payload fabrication facilities would be built at the site where the waste is located. The facilities would be owned by DOE and likely be operated by a DOE contractor. Currently, such DOE owned contractor operated facilities do not require NRC operating licenses or construction permits; however, this discussion is concerned with the types of licenses which may be required. Current discussion concerning the Waste Isolation Pilot Plant does not include licensing of the processing facility, only the repository. Regardless, similiar types of documents are required for DOE facilities anyway.

3.3.1 NRC Licensing

Since the waste treatment and payload fabrication facilities are much like a fuel reprocessing plant, such facilities would be licensed under regulations written in 10 CFR 50.* Additional requirements not presently contained in the

*See footnote, page 3-4, or Reference 3-8.

regulations could be added as an additional Appendix to 10 CFR 50. Also, if safeguard requirements are needed, these are written in 10 CFR 73.

The facilities would go through the standard licensing process, with a construction permit first being obtained, and finally an operating license. Both preliminary and final safety analysis reports would be required and the appropriate reviews would be carried out by the NRC. Specific procedures would be dependent on the regulations in force at the time of application.

3.3.2 Environmental Impact

The National Environmental Policy Act of 1969 (NEPA) requires that an environmental impact statement (EIS) be filed for major Federal actions significantly affecting the quality of the human environment. These procedures are given in 10 CFR 51. It is expected that DOE would file an environmental report and the EIS would be prepared by the NRC.

3.3.3 Criteria

Criteria for several parts of the waste processing system will have to be developed. These may include such items as allowable specific activity, payload container surface temperature, and heat flux, and contents accountability requirement. The criteria determined for the solidified waste will probably be determined by the requirements of the disposal system. Specific criteria for the operations will include allowable gaseous releases, personal exposures, radiation dose limits of processing equipment, liquid radioactive release limits, and others.

Since several aspects of the system are not unique to the space disposal option, the criteria for these aspects can be obtained from or developed in conjunction with the other options for defense HLW disposal. Those aspects which are unique such as concentration to higher specific activities, and possibly chemical and/or isotopic separation, waste form, and containerization will require the development of criteria independent of other programs.

The development of criteria will probably be carried out by contractors working on the space option, but the final specification of the criteria to be used in the system safety analysis will be specified by the NRC.

3.4 Overland Shipment

The overland shipment of the waste payload containers from the waste treatment and payload fabrication facilities to the launch site are not addressed in any detail here. Regulations for radioactive materials shipments currently exist and shipping containers, casks, can be licensed under the applicable regulations, 10 CFR 71. It should be noted, however, that the NRC does not currently license DOE casks, but DOE casks are built to NRC licensing requirements. It is expected that the NRC will, at some time in the future, license all shipping containers for radioactive materials.

The licensing and development of a shipping cask will take 3 to 5 years. Although this type of license is a standard one, the changing regulations are requiring new types of testing to prove the integrity of casks. The primary requirement will be the need to know what the cask contents will be.

3.5 Launch Site Facilities and Operations

The launch site facilities include the Nuclear Payload Preparation Facility (NPPF), a ground transport system, and Space Shuttle system including the mission operations and recovery system. There are two views on the licensing aspects of the launch site facilities and operations. The first is to view the launch site facilities and operations as a total system, as one would a reactor or fuel reprocessing facility. The second is to view the launch facilities as a site with a radioactive materials license and the Space Shuttle as a transport vehicle carrying a licensed transportation payload. In the following discussion, these views will be referred to as Options 1 and 2.

The Interagency Review Group[3-3] has recommended in their report that the NRC license all facilities for the long-term storage of radioactive waste. The question of the NRC licensing of a specified place in space must be addressed if that place is considered a facility for long-term storage of radioactive waste.

As in the case of the waste processing facility, the launch site is owned by the government and the question of NRC licensing NASA facilities must also be addressed. To be consistent with the previous discussion, in this discussion it will be assumed that the NRC may license NASA facilities. It must be assumed that NASA would apply similar criteria to launch site facilities and operations even if NRC licensing were not a question.

3.5.1 Licensing

The discussion of NRC licensing will be divided into separate discussions of Option 1 and Option 2.

3.5.1.1 Option 1

The licensing of the launch site facilities and operations as a system will require a new type of NRC license. The launch site facilities do not present a unique problem, but the licensing of a space flight mission is unique. Previously, nuclear payloads flown on space missions have not been licensed, but have been approved by the president, after extensive reviews have ensured

adequate safety. This procedure is not expected to be used for space disposal of nuclear waste. A license for space disposal missions would have to require compliance with specifically defined procedures and would limit the ability of the crew to handle unanticipated problems. However, space flights could be simulated ahead of time so that proper specific procedures could be implaced. In addition, the mission could be practiced using simulated waste containers and actual space flight to test all operations.

The specifications and regulations for the NPPF and its operations, and transporting the payload at the launch site could be handled by current regulations. A more difficult problem is encountered when an analysis of the launch system is attempted. The question arises as to whether the launch vehicle and waste payload can be analyzed together as one system.

Current regulations require the radioactive material containing package to withstand the postulated accident conditions. Mitigation of accident effects due to the presence or structure of the transport vehicle is not allowed. For example, the absorption of impact by the vehicle is not allowed to reduce the level of impact that would be seen by the cask if the vehicle were not present.

This option may be the least controversial because more of the total operation would be included under direct NRC license control. Also, this would be a two-phase licensing process with a review prior to any significant testing similar to a construction permit and then a final review before operation with actual waste material after cold testing of the system. However, this does imply that new and separate launch facilities will be required for HLW transport than are already available for other Space Shuttle operations.

3.5.1.2 Option 2

The licensing of a site for possession and handling of radioactive material and the licensing of a container for shipping materials are the methods currently used in the regulations. Operations at the NPPF are expected to be simpler than those carried out in many hot cells. The ground transport at the launch site would be allowed under the special nuclear materials license granted under 10 CFR 70. Vehicles and containers for launch site ground transport by a licensee are not licensed. The licensee must, however, comply with the radioactivity release and exposure regulations of 10 CFR 20. If the fissile and

fertile material content is below allowable limits, a license could be obtained under 10 CFR 33 since all the material handled would be considered by-product material. This licensing process is the same as is currently used for many radioactive materials operations including privately owned and operated hot cell facilities which can handle rather large quantities of spent fuel. The 10 CFR 70 license and 10 CFR 33 licenses specify the quantities of radionuclides the licensee may have while the licensee must also comply with other health and safety regulations such as 10 CFR 20, and safeguards regulations in 10 CFR 73. However, government owned radioactive material is handled under DOE regulations which are essentially parallel to the NRC regulations.

By looking at the Space Shuttle as a simple transport vehicle, such as a plane or truck, the current procedure, as applied, would be to license the payload for shipment in the Shuttle. Obviously, a new set of design criteria would have to be set up so that the payload and its contents would perform as intended under anticipated accident conditions such as a launch accident or unplanned reentry. The payload would be licensed under 10 CFR 71, which would have been amended to satisfy the criteria for space transport.

The licensing process would have to be examined closely since the types of licenses involved in this option do not normally involve the degree of public participation as is involved in 10 CFR 50 licenses. An extra effort would be needed regarding policy and environmental impact to assure public participation in the decision-making process, or the license proceeding would have to assure such participation.

3.5.2 Environmental Impact

An environmental impact statement would be required for the handling of significant amounts of radioactive materials at the launch site. Also, the potential environmental impacts of the credible accidents during mission operations would also have to be examined. In this case, reviews by NRC and other agencies would be required. This is the point where significant public participation could be included in the licensing Option 2.

3.5.3 Criteria

The development of criteria for the launch facility and operation could be a major factor in the determination of economic feasibility of the space option. These criteria may include specific limits on allowed radioactive release due to accidents and limits on the variation of the ultimate solar orbit of the waste payload. The level of risk will surely be a very important factor. The criteria on mission operations will have to be set up so that the consequences from most credible accidents will be extremely small. The entire concept may not be socially acceptable if any credible accident has severe consequences.

The possible impact of criteria on the design of system and mission operations should be examined early in the program so that potential design concepts can be examined. Therefore, criteria should be developed as soon as possible.

3.6 Major Policy Questions

Several major policy decision points will occur during the development of the space option. The first of these is a decision to proceed with the research and development required for the space option. If this decision is positive, the research required to develop the waste treatment processes for the concentration, solidification, and payload fabrication should proceed. Also, the standards, criteria, and regulations should be drafted. In conjunction with this, a draft environmental impact statement for the program should be prepared. A conceptual study of the space option should be made as well as conceptual designs of the total payload system to be carried into space on board the Space Shuttle.

Based on the information obtained, the actual construction of waste treatment and payload facilities could begin. The preliminary design of NPPF could be prepared to comply with the criteria already set up. A final program EIS on space isolation would be prepared and international issues would be identified and resolved. The discussion and resolution of international questions is critical since final disposal would not be on U.S. territory. One solution may be to make space disposal operations an international venture; that is, to allow all nations to use this method for radioactive waste disposal. Testing of systems

such as reentry, docking, and rescue systems must be carried out. These tests would allow a quantification of risk and consequences.

The next decision would be to develop and test the complete mission operation. Required launch site facility construction would begin and final testing be completed. These would lead to the final approval of routine space disposal operations.

3.7 Test Program Requirements

The major goal of the test program would be to quantify and minimize the risk involved in space disposal option. All severe accidents leading to potential unacceptable consequences should be simulated using actual hardware to aid design and show that the accident consequences are indeed known and acceptable. These may include such things as testing reentry and recovery of payloads, subjecting payload systems to fires and explosions, and other credible accidents. The credibility of the space option will be dependent on the results of these tests. The specific requirements for testing are described in more detail in Section 4.0.

3.8 Summary and Conclusions

The isolation of HLW in space will require the development of two major systems; first, a facility for the recovery, concentration, solidification, and fabrication of HLW payloads, and second, launch site facilites (e.g., NPPF) and mission operations. Specifically with respect to the launch facilities, the use of Option 2 is recommended. These systems may be licensed in some manner by the NRC. The development of good standards, criteria, and regulations will play a key role in the development and use of the space option. Finally, a clear quantification and minimization of risk and consequences will be required.

It should be possible to establish a program in such a manner that will lead to valid technically sound and socially acceptable decisions concerning the space option.

3.9 References

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4.0 FLIGHT TEST REQUIREMENTS

4.1 Introduction

The unique nature of the space disposal mission and the expected high public concern over possible release of nuclear material will likely lead to a requirement for extensive testing. This testing is expected to take several forms, including ground-based tests, flight tests of specific hardware items and an all-up flight test of the entire space disposal mission. This section describes the proposed general test philosophy and identifies a number of specific anticipated test activities. The approach and requirements discussed here are interrelated with the SR&T developments and the licensing approach discussed in Sections 2 and 3, respectively.

4.2 Test Philosophy

Two concepts dominate the proposed test philosophy. First, the test program should be as extensive as practicable to maximize public confidence and system safety. This approach will likely result in a costly test program, but, within reasonable limits, costs must be secondary to system safety in the space disposal mission. Therefore, an extensive set of ground-based tests and a number of more complex flight tests are expected. A preliminary listing of these expected tests is given in Section 4.3.

The second concept governing testing is that there is no apparent reason why any actual nuclear waste would need to be flown in space prior to the beginning of actual operations. Most tests of the container survivability with a waste payload would be conducted on the ground. Necessary flight tests of loaded containers could be conducted using simulated waste with an appropriate tracer material to monitor any release and dispersion.

4.3 Specific Test Requirements

Three categories of tests are anticipated: ground-based tests, flight tests of specific items and all-up system flight tests. A number of specific test requirements for each category are identified below. Additional test items are expected to be identified as the program develops.

4.3.1 Ground-Based Tests

As discussed in Section 3, Licensing Requirements, the primary licensing emphasis is expected to be on insuring the survivability of the container under a wide range of potential accident conditions. A number of these accident conditions can be simulated in ground tests and compliance thereby demonstrated. Based on the data of Volume II, ground tests to demonstrate container survival under the following conditions would be expected:

- Ground fires from the SRM (both from propellant fragments and split motor cases)
- Blast wave overpressure and blast fragment impacts from ET explosion
- Ground and waste impacts to simulate terminal conditions from reentry and abort.

Combinations of the above tests (e.g., fragments plus fire) may also need to be conducted. All of the above tests can be conducted in remote locations to minimize overall hazard. For the ground and water impact tests, a variety of ground conditions, water depths and impact velocities may need to be examined. The exact conditions under which the tests would be conducted would be defined as a part of the licensing criteria process discussed in Section 3 and identified in Figure 3-1. The actual tests would be conducted during the period prior to the application for license from the NRC, and the test results would be included in the supporting data accompanying the license application. Additional tests might need to be conducted during the license application hearing period to resolve specific NRC concerns.

Demonstration of container survival during reentry will probably require actual flight test drops from the Shuttle Orbiter. The waste payload/container will likely be too large to allow reentry testing under simulated upper atmospheric conditions in existing supersonic and hypersonic tunnels. However, preliminary testing of subscale payload models for various portions of the reentry environment can and should be conducted. Such tests could give preliminary evidence of payload survival and could be used to define the likely severest cases to allow actual flight tests to be reduced to the minimum needed.

A second set of expected ground-based tests would be aimed at the waste material rather than the containment systems. As previously indicated in Section 2.2, Waste Form Thermal Response, resistance to dispersion and formulation of inhalable particles are expected to be major criteria for selection of the final waste form. An extensive set of ground-based tests are expected to be conducted as a part of this selection process, and to demonstrate that the final waste form has the desired characteristics. These tests will probably be conducted in a low-density, high-stagnation-temperature hypersonic or supersonic wind tunnel facility, with special facilities for collection of the portions of the waste form samples eroded by the gas flow.

A final set of expected ground tests concerns the transportation and handling of the nuclear waste prior to launch. A number of potential accidents in the ground transportation and payload handling phase of disposal operations were identified in Section 5 of Volume II. It is expected that tests will be required to demonstrate payload intact survival under these various conditions (e.g., ground transport delay combined with loss of primary cooling, dropping of the payload in the NPPF). Further, since the performance of the transporting and payload handling crews will affect overall system safety, a series of special tests are expected to be conducted to test operator awareness and preparation. These tests would be similar to those currently given to aircraft crews and nuclear reactor operators. In such tests (which are normally given on a computer simulator, but which might have to use the actual hardware for waste disposal), the operators attempt to conduct a normal operation (reactor startup, aircraft takeoff, etc.). A number of system failure modes (e.g., engine failure) are built in the test system which can be initiated by the testing authority without the knowledge of the system operator. The operators must detect the problem and initiate the appropriate emergency procedures. A number of such tests would likely be conducted for the ground operations phase of nuclear waste disposal.

4.3.2 Flight Tests of Selected Systems

A number of specific subsystems will need to be flight tested separately prior to an overall flight demonstration of the entire waste disposal system. Three systems will need to receive specific attention: payload/container survival, payload exchange mechanisms operation, and remote rendezvous/docking. Each of these are discussed below.

As mentioned in 4.3.1, the survival of the payload/container will need to be demonstrated under several conditions. At present, it is expected that at least three tests would be required.

(1) Reentry of the payload plus reentry system from low Earth orbit

(2) Reentry of waste container alone (no reentry system but possibly with some nonreusable thermal protection) from low Earth orbit (shallow reentry simulating OTV failure shortly after ignition start)

(3) Same as 2, but with a steep reentry path simulating a seriously misdirected OTV burn.

The third case would require attaching a velocity package (probably a solid propellant motor) to the waste container to provide the simulated OTV propulsion increment. The tests would be designed to demonstrate container survival and/or to detect any container breaking and associated waste dispersion. They would make use of the ground-test program discussed in 4.3.1.

If the current baseline two-Shuttle launch profile for the waste disposal mission holds, an on-orbit payload exchange between the Orbiter and the OTV will be required. If the reentry protection system and associated shielding is to be removed prior to OTV burn (which has been assumed in all the options considered in this particular study), a mechanism for removal of these systems will be required. In both of these cases, demonstration of the operation of these mechanisms under space conditions will be required.

The final set of special flight tests would be of the remote rendezvous and docking capabilities. Since the reuse plans all are based on the use of a second OTV, the OTV and a simulated payload would be the primary test items. The tests would require at least two Shuttle launches, one for the OTV and one for the payload. The required rescue mission could take place in either near-Earth or distant locations. Both cases need to be demonstated. Near-Earth rendezvous and docking would likely use a man-in-the-loop system with continuous control. Distant rendezvous and docking would have to use an on-board autonomous system with limited ground override capabilities.

Both capabilities could probably be demonstrated in one flight test. Since it is the rendezvous and docking that is being demonstrated, the payload would not need to be actually returned to the Shuttle by the rescue OTV. Therefore, the rescue OTV propellant could be used to provide:

- Orbital transfer to the target payload in low Earth orbit
- Coarse rendezvous in low Earth orbit
- Disengagement with the payload
- Orbital transfer to the target payload in distant orbit
- Coarse rendezvous in distant orbit
- Disengagement from the payload and return to the Orbiter.

Terminal rendezvous, stationkeeping and attitude control would be accomplished by the rescue OTV reaction control system.

The target payload would also need to have a propulsive capability. It might, in fact, be a modified OTV, equipped with the appropriate docking adapter and other required equipment, e.g., transponders. It would have to perform the following maneuvers:

- Deployment from the Orbiter to the near-Earth orbit for first rendezvous and docking
- Orbital transfer to the second (distant) orbit for the second docking
- Return to the Shuttle Orbiter (optional -- probably desirable if the target is a modified OTV).

The target vehicle would have to maintain attitude stability during terminal docking. It might be required that docking with a completely inactive target be demonstrated; in that case, the target RCS should initiate a tumble rate to demonstrate rendezvous under worst case conditions.

4.3.3 All-Up Test Flight

Prior to final operating license approval, it is expected that an all-up flight test of the entire space disposal system will be required. The test would be designed to demonstrate the nominal disposal mission profile. However, as discussed previously in Section 4.3.1, it is likely that the system will also have to demonstrate its ability to discover and correct unexpected system problems. In the case of the all-up flight test, this would likely take the form of several planned simulated system failures or anomalies (e.g., an initially misoriented OTV burn which would need to be detected and terminated, with the OTV reoriented for a proper injection burn). These failures would be known to the program test managers, but not to the flight control personnel responsible for conducting the test flight. Successful demonstration of the mission profile while

overcoming the unexpected anomalies would be a major step in satisfying NRC and other regulatory requirements and in increasing public confidence in space disposal. One such flight (if successful) would be expected to be required.

4.4 Test Schedule

As indicated previously, the schedule for testing is correlated with the licensing and overall decision schedule shown in Figure 3-1. The primary test period will be during the 7-10 year period following the decision to begin major development of the waste disposal system. Some of the ground-based testing would need to occur prior to this period, and the all-up flight tests would be conducted in the 3-5 year period of final development prior to initiation of disposal operations. The expected schedule is shown below.

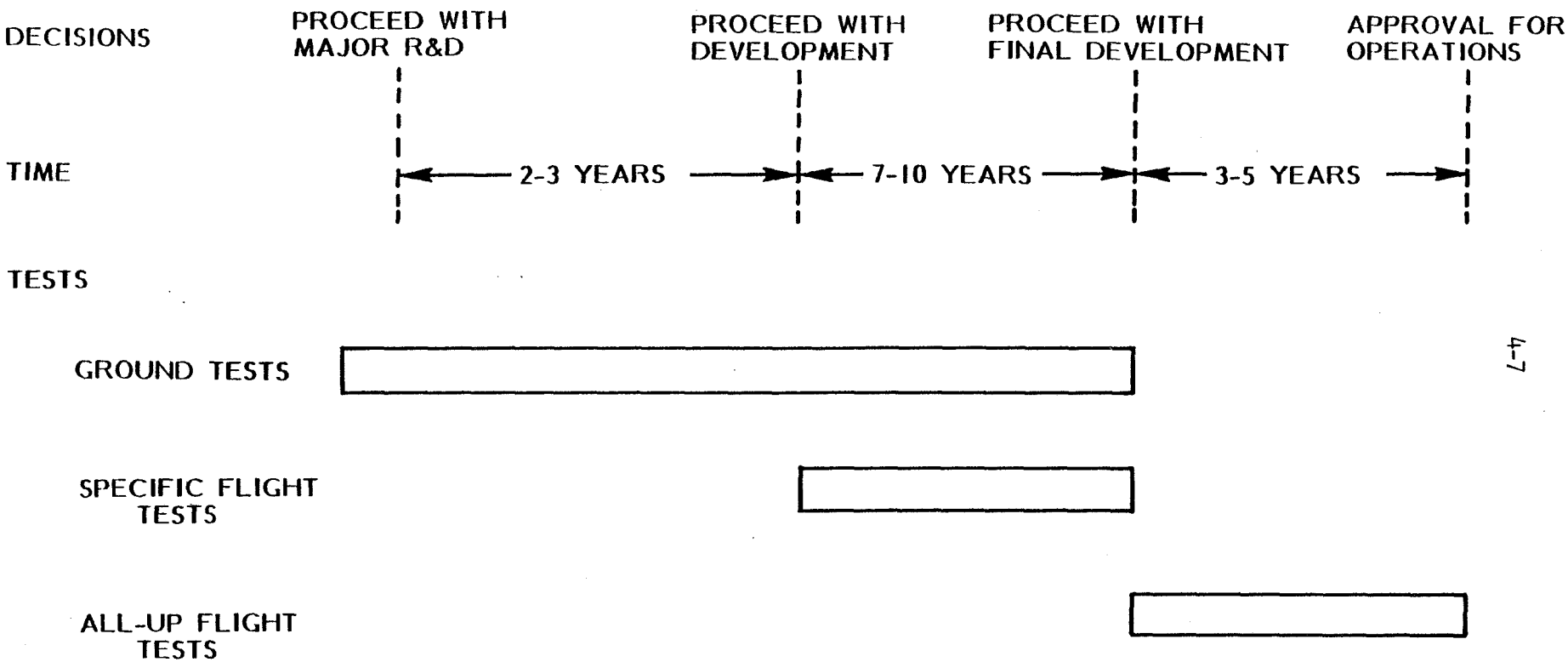

FIGURE 4-1. EXPECTED TEST SCHEDULE

APPENDIX A

ACRONYMS AND ABBREVIATIONS

APPENDIX A

ACRONYMS AND ABBREVIATIONS

CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
DOE	Department of Energy
DOT	Department of Transportation
EIA	environmental impact assessment
EIS	environmental impact statement
FY	fiscal year
FSAR	final safety analysis report
HLW	high level waste
H_2/O_2	hydrogen/oxygen
IOC	initial operational capability
JPL	Jet Propulsion Laboratory
K	thousands
KSC	Kennedy Space Center, Florida
LDEF	Long Duration Exposure Facility
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NPPF	Nuclear Payload Preparation Facility
NRC	Nuclear Regulatory Commission
OAST	Office of Aeronautical and Space Technology, NASA's
OTV	Orbital Transfer Vehicle
PSAR	preliminary safety analysis report
RCS	Reaction Control System, Space Shuttle's
R&D	research and development
RFP	request for proposal
SAI	Science Applications, Incorporated
SOIS	Solar Orbit Insertion Stage
SR&T	supporting research and technology
USEPA	United States Environmental Protection Agency

APPENDIX B

A RESEARCH AND DEVELOPMENT PROGRAM PLAN FOR THE SPACE DISPOSAL OF NUCLEAR WASTE

APPENDIX B

A RESEARCH AND DEVELOPMENT PROGRAM PLAN FOR THE SPACE DISPOSAL OF NUCLEAR WASTE

Introduction

This appendix contains a proposed three-year R&D development plan for space disposal of nuclear waste. The plan was developed by Battelle and NASA/MSFC personnel, and was published separately as a Concept Development Plan. The plan outlines a three-year R&D program to support a joint DOE/NASA decision on whether to proceed with development of a space disposal option.

A summary of the proposed three-year plan for R&D for space disposal is presented first. This is followed by detailed plans for activities in the following areas:

- Space Systems Definition and Design
- Nuclear Waste Definition and Systems Design
- Critical Technology Experiments/Testing Plan
- Impact Assessment.

Summary of R&D Plan for Space Disposal of Nuclear Waste

The R&D program is currently envisioned to consist of two phases: (I) Concept Definition (first three years) and (II) Systems Development. The Concept Definition Phase covers intensive system and requirement definitions and impact assessments. The second phase provides for systems development, assuming the first phase activities result in an affirmative program continuation decision. The emphasis in this section, while both phases are discussed, will be on the Concept Definition Phase.

Description of Concept Definition (Phase I) Plan

The R&D plans for Phase I are summarized below. Management responsibilities (DOE and NASA), schedules and required resources are summarized in this section. More detailed discussions and data are provided in later sections.

Summary of Phase I Study Activities and Objectives

The major functional activities of the three-year Phase I (Concept Definition) program are shown in Figure B-1. Primary research functions during this period are:

- Space systems definition and design
- Nuclear waste systems definition and design
- Critical technology testing
- Impact assessments (health, safety, socioeconomic, sociopolitical, etc.)
- Program planning.

The first-year Phase I program activities will build upon the basis of previous study results with the emphasis on further defining space and nuclear waste systems, identifying critical technology, and assessing safety and environmental impacts. Space system studies will further define the baseline space disposal concept including: conceptualization of unique systems; the characterization of modifications to existing launch systems and facilities; the identification of critical technologies; and the development of preliminary cost and system reliability data. Nuclear waste systems studies will be conducted to investigate the nuclear waste treatment system capabilities and costs, the character of nuclear waste mixes and waste forms, waste packaging requirements to support space disposal of nuclear wastes, and definitions of ground systems unique to the space disposal concept including transportation to the launch site. An assessment of the safety, environmental impact and other issues of space and nuclear waste systems, operations and facilities will parallel the first year of systems studies. The output of this first year study activity will be: (1) identification of critical technologies, (2) a preliminary draft environmental impact assessment, and (3) the selection and definition of a preliminary space disposal concept.

The second-year Phase I efforts will emphasize preliminary designs of the unique space and nuclear waste systems and facilities, the design of research experiments necessary to test critical technology areas, and continued assessments of human health and safety and socioeconomic impacts. As the design definition of the concept matures, the availability of more detailed cost

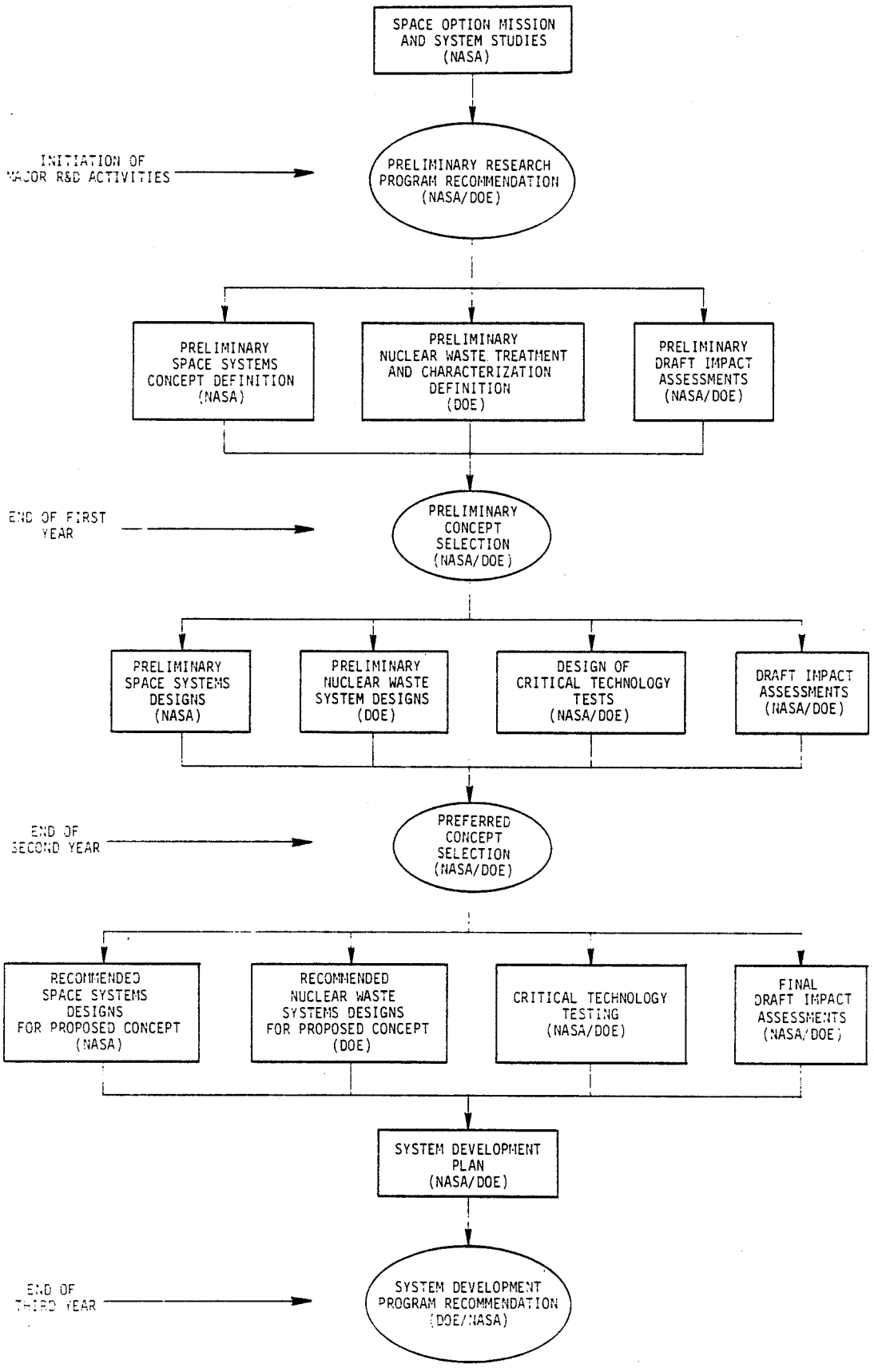
SPACE OPTION MISSION AND SYSTEM STUDIES (NASA)
INITIATION OF MAJOR R&D ACTIVITIES
PRELIMINARY RESEARCH PROGRAM RECOMMENDATION (NASA/DOE)
PRELIMINARY SPACE SYSTEMS CONCEPT DEFINITION (NASA)
PRELIMINARY NUCLEAR WASTE TREATMENT AND CHARACTERIZATION DEFINITION (DOE)
PRELIMINARY DRAFT IMPACT ASSESSMENTS (NASA/DOE)
END OF FIRST YEAR
PRELIMINARY CONCEPT SELECTION (NASA/DOE)
PRELIMINARY SPACE SYSTEMS DESIGNS (NASA)
PRELIMINARY NUCLEAR WASTE SYSTEM DESIGNS (DOE)
DESIGN OF CRITICAL TECHNOLOGY TESTS (NASA/DOE)
DRAFT IMPACT ASSESSMENTS (NASA/DOE)
END OF SECOND YEAR
PREFERRED CONCEPT SELECTION (NASA/DOE)
RECOMMENDED SPACE SYSTEMS DESIGNS FOR PROPOSED CONCEPT (NASA)
RECOMMENDED NUCLEAR WASTE SYSTEMS DESIGNS FOR PROPOSED CONCEPT (DOE)
CRITICAL TECHNOLOGY TESTING (NASA/DOE)
FINAL DRAFT IMPACT ASSESSMENTS (NASA/DOE)
SYSTEM DEVELOPMENT PLAN (NASA/DOE)
END OF THIRD YEAR
SYSTEM DEVELOPMENT PROGRAM RECOMMENDATION (DOE/NASA)

FIGURE B-1. PHASE I (CONCEPT DEFINITION) PROGRAM OVERVIEW

and programmatic data will permit more emphasis on socioeconomic and sociopolitical impacts in the impact assessment activity. Also, preliminary system designs and development of system reliability data will allow improved assessments of accidents. The major outputs of this activity will be: (1) the selection of a preferred concept (or concepts) for disposing of nuclear wastes in space, (2) the design of research experiments for critical technology areas, and (3) the documentation of a draft environmental impact assessment.

The third-year Phase I effort will consist of further refinement of the preferred concept. Emphasis will be on: (1) preparing recommended designs for the proposed concept, (2) critical technology testing, and (3) preparation of comprehensive environmental impact and system safety assessments. Near the end of these activities, study results will be integrated into a total systems development plan. NASA and DOE would then provide specific recommendations to the Administration.

On the basis of these recommendations, supported by the integrated results of the Phase I study program and other pertinent factors, it will be possible for DOE and NASA to recommend follow-on activities (if any) to the Administration.

Summary of Phase I Resources (Preliminary)

The following table provides a brief summary of the resources allotted to both DOE and NASA for carrying out the proposed effort.

	AGENCY MANPOWER (MAN-YEARS)				CONTRACTED R&D FUNDING ($K, 1978)			
	1ST YEAR	2ND YEAR	3RD YEAR	TOTAL	1ST YEAR	2ND YEAR	3RD YEAR	TOTAL
DOE								
Nuclear Waste Definition and System Design	6	7	4	17	1000	1000	300	2300
Critical Technology Testing	0	3	4	7	0	1000	400	1400
Impact Assessments	2	3	3	8	200	1000	500	1700
Integration and Planning	2	2	4	8	0	0	0	0
TOTAL	10	15	15	40	1200	3000	1200	5400
NASA								
Space Systems Definition and Design	7	9	7	23	1300	1000	300	2600
Critical Technology Testing	0	2	3	5	0	1000	500	1500
Impact Assessments	2	3	3	8	500	1000	500	2000
Integration and Planning	1	1	2	4	0	0	0	0
TOTAL	10	15	15	40	1800	3000	1300	6100

Brief Description of System Development Phase (II) Plan

The objectives of the System Development Phase (II) of the R&D program are to develop and demonstrate the systems, facilities and operations necessary to implement the disposing of nuclear waste in space. Specific objectives of individual programs will be developed as a part of the program plan from the Concept Definition Phase. The initial operational capability (IOC) for disposing of nuclear waste in space is envisioned to be in the early 1990's. Leading up to this date, the major activity areas are expected to include (see Figure B-2):

- Nuclear waste payload design and development
- Solar orbit insertion stage design and development (kickstage)
- System integration and checkout
- Flight demonstration testing
- Licensing activities.

A separate NASA development which will be needed for this mission is the OTV development. It is projected that the OTV will be available by late 1988 to begin system integration and checkout (see Figure B-2).

Detailed management, schedules and resource information will be developed as part of the systems development plan (see Figure B-1). No detailed information can be presented at this time. Figure B-2 indicates the current best estimate for key milestone dates for space disposal.

Space Systems Definition and Design Plan

The studies of nuclear waste disposal in space over the past several years have investigated a variety of different approaches. Results of these studies have provided valuable insights to each successive study activity in such a way that systems approaches have been converging rather than diverging. A number of options to the current baseline concept exist (see Figure B-1), but they are generally oriented toward improving the baseline rather than displacing it. The space systems definition and design activities described in this section are based upon a plan developed around the current baseline and other favorable options already described. Only the Concept Definition Phase (I) of the R&D Program is discussed below.

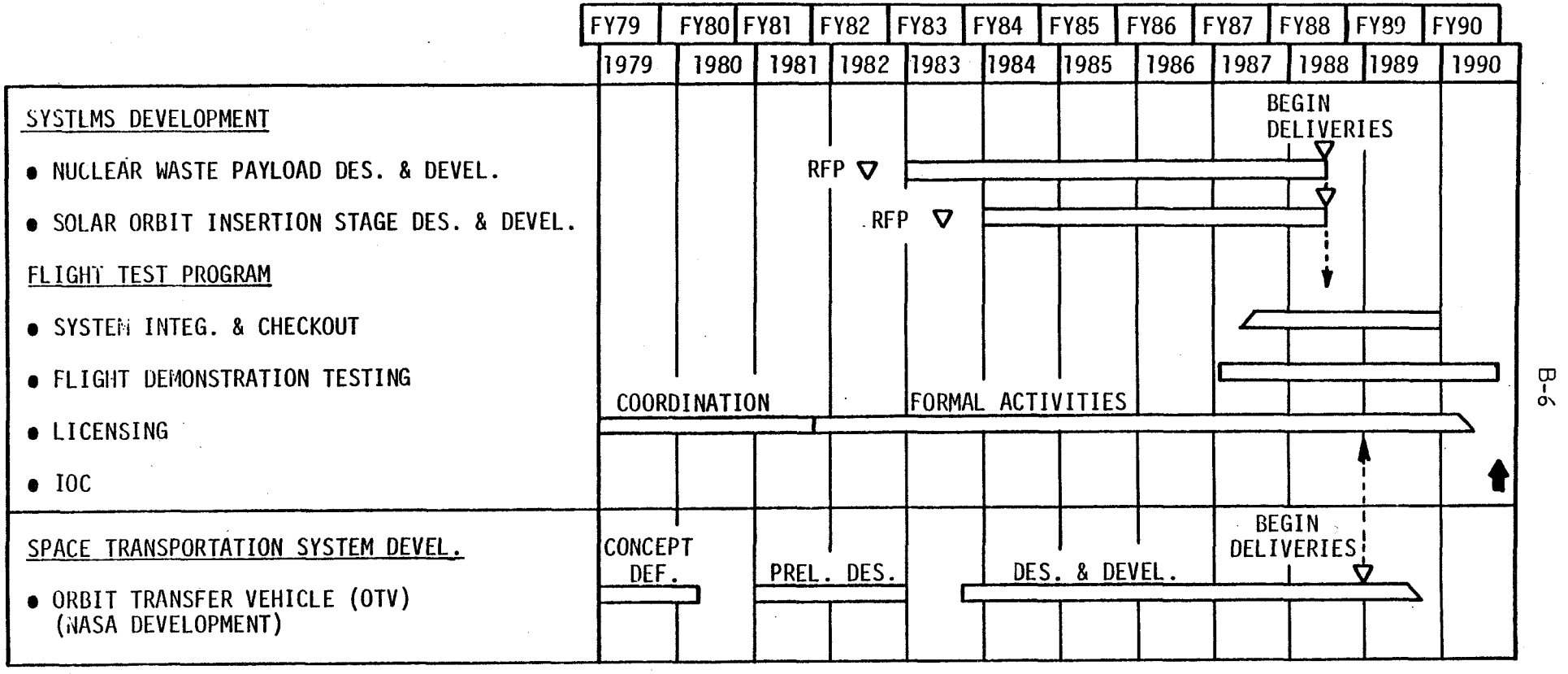

FIGURE B-2. SUMMARY OF PRELIMINARY SCHEDULE FOR SYSTEM DEVELOPMENT ACTIVITIES (PHASE II)

Objectives

The primary objectives of the space systems definition and design activity are to: (1) provide conceptual and preliminary design and operations definitions for the space systems and facilities required to safely carry out a space disposal mission; (2) identify and evaluate critical space technology issues; (3) develop space system cost and reliability data; and (4) develop detailed program plans for space systems and facility development, following a program continuation decision at the end of the three-year period.

Approach

Three years of space system studies are identified in Figure B-1. The space system studies will involve: system conceptualization; identification of critical technologies; preliminary systems design; development of preliminary operational procedures; development of reliability and cost data; and various system trade studies. Space systems, supporting facilities, and operations that will be studied include the following:

- Any nuclear waste containment system that is transported into space (e.g., primary container, radiation shields and reentry system)
- Any subsystem which supports the containment system (e.g., cooling, telemetry, RCS, flotation, etc.)
- A nuclear payload preparation facility and other support equipment at the launch site
- Launch support facilities
- Prelaunch operations
- Booster vehicles and operations
- Upper stage vehicles and operations
- Rescue vehicles and operations.

During the Phase I program, early space systems definition activities will interrelate closely with the nuclear waste treatment and packaging studies. Certain space system requirements will be defined through NASA/DOE trade studies. Requirements for high levels of safety and minimal environmental impacts will be incorporated into concept baseline requirements.

State-of-the-art and projected advanced nuclear waste treatment and packaging technologies will have to be considered in evaluating possible payload concepts. Highly concentrated high-level defense waste derived from advanced nuclear waste treatment will impose significant thermal and nuclear radiation environments on the payload and related support systems. The character of the nuclear waste is expected to be defined by the DOE at the end of the first year of R&D activities.

Once the basic concepts of defense nuclear waste treatment and packaging for space disposal have been resolved, the subsystem requirements can be established and candidate subsystems defined. Design, cost and reliability analyses are to be performed on these subsystems to derive a baseline space system concept. Evolution of this baseline through concept definition system studies will lead to recommendation of a preliminary concept definition (see Figure B-1).

The second year of effort will be oriented toward preliminary design definition of systems and subsystems; identification, definition, and recommendations for experimental developments of critical technologies; and analytical accident response analyses to be performed on containment systems. The output of the baseline space system studies at this point will include: (1) a technological status report at the system and subsystem level; (2) an assessment of technological uncertainty; (3) a system reliability assessment; (4) a cost assessment; and (5) assessment of implementation schedules. A preferred concept will be selected for further study by NASA and DOE, after a review of the appropriate in-house and contracted impact assessments have been completed.

The next stage of the Phase I program will be to subject the results of the program to safety and environmental impact assessments and the results of the critical technology testing activities. This is expected to occur near the middle of the third year so that sufficient reaction time would exist so that critical space system design deficiencies can be improved, if necessary. Once the recommended designs of space systems have been established, work will continue to define a space system development plan.

Management

Management for all space system studies will be with NASA. The Energy Systems Division, Office of Aeronautics and Space Technology (OAST) is

responsible for overall coordination of the NASA activities. The NASA/Marshall Space Flight Center will be the coordination center for technical aspects of space systems studies.

Schedule

The overall schedule for the conduct of the space systems definitions studies is presented in Figure B-1 together with the other major program milestones. Major program reviews and reports related to the outputs supporting the major program milestones will occur one to two months prior to these milestones. Working review meetings will occur as required to support these milestones.

Resources (Preliminary)

Both direct NASA manpower and R&D funding requirements are shown below for space systems studies.

	FISCAL YEAR		
	1ST YEAR	2ND YEAR	3RD YEAR
NASA Manpower (man-years)	7	9	7
Contracted R&D ($M)	1.3	1.0	0.3

Nuclear Waste Definition and Systems Design Plan

Most ot the previous studies of the space disposal of nuclear wastes have considered the disposal of nuclear waste from U.S. commercial power reactors. Recently, the DOE has directed NASA to consider only the disposal of high-level defense wastes that are stored at Hanford, Savannah River and Idaho Falls. To provide a data base for concept definition and mission design, the high-level defense waste must be characterized with respect to radionuclide composition, chemical composition, and waste form. This information will serve as a basis for thermal calculations, radiation shielding requirements, payload

sizing, accident analyses, and environmental impact assessments. The biggest problem facing space disposal of high-level defense waste, however, is the tremendous mass of inert materials which have been added to the waste to facilitate tank storage. Removal of this inert material and conversion to a form having a high waste loading will result in fewer Space Shuttle flights and large cost savings.

The nuclear waste definition and system design activities described in this section are based upon a plan developed around the current baseline already described. Only the Concept Definition Phase(I) of the R&D Program is discussed below.

Objectives

The primary objectives of the nuclear waste definition and systems design activities are: (1) provide conceptual and preliminary design and operations definitions for high-level defense nuclear waste removal from storage, treatment to the desired waste mix and form, packaging techniques, and transport to the launch site; (2) identify critical technological issues; (3) develop cost and system reliability data; and (4) define detailed program plans for development of the proposed nuclear waste systems and facilities, following a program continuation decision at the end ot the three-year R&D period.

Approach

Three years of nuclear waste system studies are portrayed in Figure 2-1. These studies will involve: system conceptualization; identification of critical technologies; preliminary systems design; development of preliminary waste treatment and handling procedures; development of other operational procedures, involving for example, packaging and transportation; development of reliability and cost data; and various trade-off studies. Considerable interaction between these studies and space system studies are required to effect a productive overall study.

Major areas of study have been identified as follows:

- Waste mix characterization
- Waste form definition
- Treatment systems
- Packaging techniques
- Transportation shipping cask design.

Presently, there are at least four major categories of high-level defense waste. Studies to establish the character of these wastes and their implications to container systems design, and other space systems designs are required early in the Concept Definition Phase.

The waste mixes are presently in the form of damp salt cake, liquor, sludges and calcine (Idaho Falls only). For space disposal, all of these forms must be converted to a form suitable for disposal (calcine is the current baseline). Because the defense waste has been stored for many years, allowing the decay of the short-lived isotopes, the waste will be relatively cool compared to commercial nuclear waste. The cooler defense waste allows for less complicated handling and shipment requirements. The primary problem area associated with the current technology approach to defense waste is the relatively high percentage of inerts in the waste. Substantial study will be required to understand more fully the implications of improving the nuclear loading of the waste form.

The defense waste payload fabrication facilities will provide cells for loading of the waste into containers; closing, sealing, inspecting, and decontaminating the container; and inserting it into the radiation shield assembly for transportation to the launch site. Each cell will have provisions to connect the waste container to an auxiliary cooling system as necessary. Each site will provide interim storage facilities for a number of shielded waste packages and facilities for shipping cask handling and rail car loading in closed restricted areas. The container for the nuclear waste will be designed to meet the specifications imposed by both the ground handling and space transportation requirements.

For transportation from the waste fabrication facility to the launch site, the waste containers and associated flight-weight shielding will be designed to be housed in a shipping cask which will afford additional shielding, thermal and impact protection to meet NRC/DOT regulations. The cask will eventually

have to be licensed by NRC. The cask will be designed to be transported on a specially designed rail car to adequately support and distribute the weight of the cask and provide acceptable tiedowns. In addition, the rail car will be designed to carry an auxiliary cooling system to reliably cool the waste package.

Management

Management of all nuclear waste definition and system design studies will rest with DOE. Various DOE laboratories are expected to be involved.

Schedule

The overall schedule for the conduct of the nuclear waste definition and system design studies is presented in Figure B-1 together with major milestones. Major program reviews and reports related to the outputs supporting the major program milestones will occur one to two months prior to these milestones. Working review meetings will occur as required to support these milestones.

Resources (Preliminary)

Both direct DOE manpower and R&D funding requirements are shown below for the nuclear waste definition and systems studies.

	FISCAL YEAR		
	1ST YEAR	2ND YEAR	3RD YEAR
NASA Manpower (man-years)	6	7	4
Contracted R&D ($M)	1.0	1.0	0.3

Critical Technology Experiments/Testing Plan

Critical technology experiments and testing are expected to play a vital role in the evaluation of concepts/systems that are proposed for the

nuclear waste disposal mission. Although these experiments and tests have not been defined at present, a preliminary list is presented below. Only critical technology experiments and testing believed to be necessary for the Concept Definition Phase (I) are discussed. Testing and demonstrations of technology and systems will also be required during the systems development phase; these are not discussed here.

Objectives

The primary objective of the critical technology experiments and testing activity is to verify that certain critical technologies, which have not been demonstrated to the degree desired for the space disposal activity, will be tested and demonstrated.

Approach

During the first year of systems studies (both space and nuclear waste), critical technologies will be identified. The study priorities will be assigned through a NASA/DOE evaluation process. A preliminary list of critical technology areas is presented below, along with assigned agency responsibility.

- Waste treatment/inerts removal (DOE)
- Waste form production (DOE)
- Waste form environmental response (DOE)
- Payload fabrication techniques (DOE)
- Materials compatibility (NASA/DOE)
- Containment system accident environment response (NASA/DOE)
- Effects of radiation on various space systems (NASA)
- Docking system mechanisms (NASA)
- Deep space rescue techniques (NASA).

As determined from the above list, many of these relate to system safety.

Management

Management of critical technology experiments and testing will rest with the appropriate responsible agency (for examples, see above).

Schedule

The milestone schedule for critical technology experiments/testing activity is shown in Figure B-1. The identification and evaluation of these technologies will occur in the first year. During the second year research experiments/tests will be designed; these will be carried out during the third year. The results of these tests will be incorporated into the proposed concept and system development plan recommendation.

Resources (Preliminary)

Both direct NASA and DOE manpower and R&D funding requirements are shown below for critical technology testing.

	FISCAL YEAR		
	1ST YEAR	2ND YEAR	3RD YEAR
DOE			
Manpower (man-years)	0	3	4
Contracted R&D ($M)	0	1.0	0.4
NASA			
Manpower (man-years)	0	2	3
Contracted R&D ($M)	0	1.0	0.5

Impact Assessment Plan

This section describes the various impact assessments which are required to determine the overall acceptability of the space disposal mission. Four basic impact assessments have been defined for analysis. These are:

(1) Safety, environmental and health

(2) Socioeconomic

(3) Sociopolitical

(4) Terrestrial disposal systems.

Introduction

Safety, Environmental and Health Impact Assessment

The environmental impact assessment of a nuclear waste disposal in space program will be a vital part of the decision-making process. In general, space disposal of nuclear waste exhibits an environmental risk which is higher in the short-term than for the long-term. The higher short-term risk is associated with possible transport accidents. Ultimately, and prior to a program commitment, the long-term and short-term risks of various combinations of terrestrial and space disposal approaches will be evaluated and compared. For space disposal to be included as a part of the preferred option, the long-term environmental risks of space disposal must be less than the long-term risk of using terrestrial isolation options only. A plan for dealing with the environmental impact factors and risks, associated with a nuclear waste disposal in space study, is contained in this section.

Socioeconomic Impact Assessment

Space nuclear waste disposal will have potentially major impacts or interfaces in a number of socioeconomic areas. It will be necessary to analyze issues and to have socioeconomic data, assessment results, and proposed approaches available for discussions with other Federal agencies, public groups and eventually, international bodies or agencies.

The economic impact of space nuclear waste disposal will need to be defined using cost data developed by the systems studies. Although the space nuclear waste concept appears to be achievable primarily with existing technology and without undue commitments of national or worldwide resources, there are a number of required new developments (e.g., payload container, nuclear waste payload handling facililties at KSC), whose costs must be defined. The basic concept of space nuclear waste disposal is to transport only high-level waste. This approach leads to dense, highly concentrated payloads consistent with the economics of space transport. The waste level and associated flight rates at which the concept economics would appear to be attractive need to be determined.

Sociopolitical Impact Assessment

Experience to date indicates that space nuclear waste disposal concepts will undergo a vigorous review process involving public, regulatory and international acceptance. Difficulties encountered in these areas, particularly regarding U.S. public acceptance, will likely be a major determinant of whether, when, and how space disposal is implemented.

Effects on Terrestrial Disposal Systems

Since the space nuclear waste management concept is intended to augment terrestrial disposal approaches, consideration must be given to how the space disposal operations would impact terrestrial approaches, both in terms of required interfaces and in terms of items such as common facilities and site requirements.

Objectives

The primary objectives of the environmental impact assessment effort are: (1) to evaluate the magnitude of the long and short-term environmental risks attributed to accidents and/or malfunctions; (2) to evaluate the environmental impact of normal operations; (3) to provide an environmental impact assessment (EIA); and (4) to establish an information base that would be used in a total comparative assessment.

The primary objectives of the investigation of the socioeconomic and sociopolitical issues are: (1) to determine the extent to which results in each area could significantly affect the development of space nuclear waste disposal; and (2) to develop necessary analyses and data bases required to enable NASA/DOE management to deal effectively with these critical areas.

The objective ot the assessment of impacts to the terrestrial disposal options caused by the implementation of a space disposal option is to quantify overall risks and costs of the various options.

Approaches

The technical approaches of each assessment area are discussed below. Figure B-1 provides a general guide to the timing of the various impact assessments.

Environmental Impact Assessment

The *nuclear waste management in space concept evaluation* methodology provides for interaction with the systems definition and critical technology testing activity. Prior to the first milestone (preliminary concept selection), a preliminary environmental impact assessment (EIA) is to be prepared by DOE. Prior to each subsequent milestone (see Figure B-1), the EIA is to be updated and improved by DOE as new information becomes available from the systems safety studies. Throughout the study, environmental impact and safety are of utmost concern; therefore, appropriate communication among the systems and environmental assessment studies is essential. At the time of final program recommendations a draft environmental impact statement for the recommended program will be issued (based on a recommendation to proceed with development).

The key environmental impact issues are listed below for each of the three environmental impact study areas. These are then followed by brief discussions of each environmental impact study area. Impacts to: (1) public health and safety; (2) worker (including ground and flight crews) health and safety; and (3) ecosystems are addressed. Emphasis will be placed on the assessment of credible accidents, since: (1) the long and short-term environmental risks will depend mostly on accident probabilities and consequences and (2) it has been shown that for nominal launch rates normal operations do not pose significant environmental risk.

Nuclear Waste Payload Fabrication

- Impacts from normal and possible accidental radioactive material releases into the environment

Terrestrial Payload Transport and Ground Handling

- Impacts from possible accidents during transport and ground handling

Space Transport of Waste Payload to Space Destination

- Impacts from possible Space Shuttle launch and recovery accidents
- Launch constraints
- Impacts from possible payload reentry.

Nuclear Waste Payload Fabrication (DOE). The environmental impacts of nuclear waste payload fabrication arise from: (1) development, testing and fabrication of hardware and facilities; (2) release of nonradioactive materials into the environment with impacts to the public and ecosystems; (3) radiation exposure to workers; (4) use of natural resources; and (5) the occurrence of accidents during the fabrication and waste packaging process. The environmental impacts of these types of activities will be studied by DOE.

Terrestrial Payload Transport and Ground Handling (DOE). The environmental impacts of terrestrial payload transport and ground handling arise from: (1) development, testing, and fabrication of special rail cars, transport casks, and ancillary equipment; (2) radiation exposure to workers and the public; (3) use of natural resources; and (4) occurrence of transportation accidents while enroute from the Nuclear Payload Processing Facility (NPPF) to the launch site. The major thrust is expected to be in the assessment of transportation accidents. The DOE will be responsible for these studies.

Space Transport of Waste Payload to Space Destination (NASA). The environmental impacts of space transport of the payload from the Earth's surface to its space destination result from: (1) development, testing, and construction of related hardware and facilities (NPPF and possibly launch pads at Kennedy Space Center - KSC); (2) normal operations of the Shuttle and OTV systems; (3) radiation exposure to launch support and flight crews; (4) use of natural resources; (5) accidents involving the launch vehicle; (6) accidents involving the reentry of protected and unprotected nuclear waste containers; and (7) accidents which could occur en route to the space destination. NASA will provide the assessment of impacts resulting from these activities.

Socioeconomic Impact Assessment

Socioeconomic considerations encompass those elements of the program that affect people and their environment socially and economically; these ramifications can be viewed from national and regional/local standpoints. The parameters through which these impact levels can be estimated include investments/expenditures in various economic sectors; employment needs and location; employee demands for goods and services; changes in community composition/character; etc. Studies should be conducted to assess these and the full-range of socioeconomic impacts that are anticipated with the space disposal option.

The DOE will be responsible for studying the socioeconomic impacts of nuclear waste payload fabrication and terrestrial payload transport activities; the NASA will be responsible for assessing the socioeconomic impacts of the space disposal activity beginning with the payload arrival at the launch site and carrying through until the payload reaches its final destination. Output from these studies will be integrated into the environmental assessment documentation of which the DOE has overall responsibility.

Sociopolitical Impact Assessment

In addition to the traditional socioeconomic parameters usually considered, some examination of sociopolitical implications of the space disposal option is needed. The unique characteristics of this disposal alternative have political overtones which are significant. Major elements of the sociopolitical assessment would include:

Public Acceptance

- Perceived hazards
- Relative acceptability
- Potential approaches

International Considerations

- Pertinent treaty obligations
- International law
- International public acceptance

Regulation/Licensing

- Roles of existing regulatory groups
- New roles/responsibilities
- Approaches to expedite

Nuclear Proliferation

- Waste processing/handling vulnerability
- Minimization approaches.

Study responsibilities between NASA and DOE for sociopolitical impact assessments have not yet been determined.

Public Acceptance. The issue of public acceptance of the space disposal option needs to be examined carefully, since it can dramatically influence the real feasibility of implementation. This study should identify the major issues that will exist in the public mind regarding space disposal. Public in this case is used in a general sense to refer to both the general public and various organized special-interest groups. The determination of these attitudes will have to be conducted using scientific sampling techniques and in such a manner as to not provoke premature adverse reactions.

Emphasis in the public acceptance study should be placed on determining the perceived hazards and associated issues regarding space disposal. These perceived hazards may differ significantly from the actual hazards, but are the issues that will have to be dealt with to gain public acceptance. The concept of space disposal will likely be new and novel to most groups and will involve relatively subtle considerations such as the right to use various portions of the space environment as disposal regions. The relative public acceptability of terrestrial versus space disposal should also be measured, since it may influence the final choice on the mix of terrestrial and space disposal approaches.

The study also should examine possible approaches for increasing the public acceptability of space disposal. These could include both efforts designed to improve public knowledge of space disposal and possibly systems design and operational changes that would increase public confidence.

International Considerations. The study of international considerations will examine likely attitudes and perceived hazards identified with space disposal by the non-U.S. public, including various foreign special-interest

groups. Special attention will need to be given to the wide range of such groups which include international groups such as scientific societies and various political action groups. The possibility of space disposal operations being an attractive target for terrorist operations should be considered.

A second area of emphasis in this study will be the international legal framework that may affect space disposal. Pertinent U.S. treaty obligations (e.g., the treaty on exploration and use of outer space) and aspects of international law (e.g., existing law on salvage and liability) will need to be reviewed and any resultant effects on proposed space disposal system approaches identified.

Regulation/Licensing. A study of the likely roles of regulatory agencies and requirements for licensing will also be needed. This study should identify the roles likely to be played by existing regulatory agencies, as well as possible new roles/responsibilities for other groups such as the Advisory Committee on Reactor Safety. Any likely areas of conflict between the regulatory groups should be identified. A schedule should be prepared outlining the anticipated regulatory review/licensing proceedings and data submission requirements. Long lead review and data submission requirements should be identified, and approaches to expedite the entire procedure suggested.

As part of this study, the specific issues listed below should be considered:

- Will the concerns of the EPA/CEQ toward waste disposal in space go beyond the Earth-based effects from booster flights and terrestrial disposal?
- Can we anticipate an international environmental authority analogous to the International Atomic Energy Agency?
- Will NRC develop regulations for packaging waste for space disposal?
- Will NRC regulate KSC handling facility for nuclear waste disposal?
- Is the Interagency Nuclear Safety Review Panel the authority for space transport of nuclear waste payloads?
- Will Arms Control and Disarmament Agency have a role in decision making?

- Should space disposal be a consideration in international nuclear fuel cycle evaluation?
- What would be the restrictions on nuclear material disposal in space imposed by international treaty arrangements?
- At what stage should formal dialogue be initiated with all agencies?
- Will Advisory Committee on Reactor Safety be involved?

Nuclear Proliferation. Potential proliferation of fissionable materials is not expected to be a major problem if space disposal is limited to defense wastes only. However, if commercial wastes are to be handled at some time, then the issue of nuclear proliferation will need to be considered. If the system definition proceeds without reference to this issue, an approach may be defined and possibly even developed and implemented which is incapable of eventually delivering commercial wastes because of unacceptable proliferation risks.

This study needs to concentrate on two specific issues. First, the choices of waste form and associated processing and handling procedures need to be examined in the context of their vulnerability to incidents (e.g., theft, transportation accidents, abort recovery intercept) leading to proliferation of fissionable materials. Second, modified or new approaches which could minimize the possibility of nuclear proliferation should be identified.

Terrestrial Disposal Impact Assessment

Since it is assumed that space disposal will augment terrestrial disposal, the systems definition studies will necessarily define a number of interfaces with the terrestrial disposal system. As an example, the waste must be chemically separated and processed into forms proper for each disposal approach. The processing for each may use common or collocated facilities. To insure that the interface definition process considers the impacts on both the space and ground disposal systems, a specific study to determine and track effects on terrestrial disposal is required.

This study will make extensive use of existing DOE data and will involve substantial inputs from DOE personnel, particularly in the Office of Waste Management. Personnel from this study will need to coordinate with the systems definition studies, through participation in the study reviews and other coordinating meetings. The topics to be covered in this study are:

- Definition of common facilities for handling, processing and packaging of waste
- Definition of storage, transportation and security interfaces for waste handling
- Determination of impact of space disposal options on terrestrial disposal requirements, particularly cost of terrestrial disposal and associated resource requirements, such as site characteristics and land requirements.

Management

The program elements within the impact assessment area are the responsibility of both DOE and NASA, with the DOE assuming the lead role for assessing the impacts of nuclear waste systems and terrestrial transport to the launch site and NASA assuming the lead role for assessing space systems, including ground handling at the launch facility. The overall responsibility for the integration of assessment data for the purposes of producing safety and environmental impact assessments will rest with the DOE.

Schedule

The overall schedule for conduct of the impact assessments is indicated in Figure B-1 along with identification of other major program milestones. Because of the high degree of interaction of these studies, they will need to be conducted in parallel and with closely coordinated schedules. Major program reviews and reports related to impact assessments will occur in one or two months prior to the year end milestones indicated in Figure B-1. Reviews of impact assessment efforts will be held on a quarterly basis. Interim program reports will be limited to documentation presented in the quarterly reviews.

Environmental Impact Assessments (which will include assessments of total system safety) will be prepared as follows:

- Preliminary Draft EIA -, September of 1st year
- Draft EIA -, September of 2nd year
- Final EIA -, September of 3rd year.
- Draft EIS -, Late in 3rd year (based on recommendation to proceed with development).

Resources (Preliminary)

Both direct NASA and DOE manpower and R&D funding requirements are shown below for the various impact assessment activities.

	FISCAL YEAR		
	1ST YEAR	2ND YEAR	3RD YEAR
DOE			
Manpower (man-years)	2	3	3
Contracted R&D ($M)	0.2	1.0	0.5
NASA			
Manpower (man-years)	2	3	3
Contracted R&D ($M)	0.5	1.0	0.5